Journal of Agriculture and Natural Resources (2020) 3(1): 117-132
ISSN: 2661-6270 (Print), ISSN: 2661-6289 (Online)
DOI: https://doi.org/10.3126/janr.v3i1.27105

Research Article

Incidence and predation rate of hornet (*Vespa* spp.) on European honeybee (*Apis mellifera* L.) apiary at mid-hill areas of Lalitpur district, Nepal

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Received: July 08, 2019; Accepted: September 28, 2019; Published: January 7, 2020

ABSTRACT

Predatory hornets are considered as one of the major constraints to beekeeping industry. Therefore, its incidence and predation rate was studied throughout the year at two locations rural and forest areas of mid-hill in Laliptur district during 2016/017 to 2017/018. Observation was made on the number of hornet and honeybee captured by hornet in three different times of the day for three continuous minutes every fortnightly on five honeybee colonies. During the study period, major hornet species captured around the honeybee apiary at both locations were, *Vespa velutina* Lepeletier, *Vespa basalis* Smith, *Vespa tropica* (Linnaeus) and *Vespa mandarina* Smith. The hornet incidence varied significantly between the years and locations along with different observation dates. Their incidence and predation rates were low in early spring and summer that gradually increased with the highest peak in October and November in both locations. The maximum predation was on mid-November (62.07%) and early-November (53.49%) at rural and forest locations, respectively during 2016/017. In 2017/018, the highest predation was on early-November (70.27%) at rural area while it was in mid-November (58.62%) in the apiaries near the forest area. The population of hornet was considerably higher at forest areas and their incidence around the honeybee apiaries were negatively correlated with rainfall. Hence, assessment of the temporal and spatial population variations and predation rates along with weather parameters is helpful in to develop sustainable management plans of the hornet in apiary.

Keywords: Beekeeping, *A. mellifera*, *Vespa* spp., Incidence, Predation, Locations

Correct citation: Bista, S., Thapa, R.B., K.C., G.B., Pradhan, S.B, Ghimire, Y.N., & Aryal, S. (2020). Incidence and predation rate of hornet (*Vespa* spp.) on European honeybee (*Apis mellifera* L.) apiary at mid-hill areas of Lalitpur district, Nepal. *Journal of Agriculture and Natural Resources*, *3*(1), 117-132. DOI: https://doi.org/10.3126/janr.v3i1.27105

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INTRODUCTION

Honeybees are one of the few insects, which are beneficial to human beings. Beekeeping has been practiced in Nepal since the prehistoric times especially for honey production and extra income generation. Honeybees also help to enhance agricultural productivity, conserve biological diversity and provide various ecosystem services including ensured pollination services. Among five species of honeybees present at the country (*Apis florea* Fab., *Apis cerana* Fab., *Apis mellifera* Lin., *Apis dorsata* Fab. and *Apis laboriosa* Smith, *A. cerana* and *A. mellifera* are the only domesticated species (Bista & Lakhey, 2017). The oriental hive bee, *A. cerana*, native to Nepal, is common throughout the country as stationary beekeeping. With the introduction of high yielding European honeybee, *A. mellifera* suitable for plain and foothill areas, the commercial beekeeping has started in Nepal. The prevalence of diversified bee flora and suitable climatic condition has shown tremendous potentiality for beekeeping enterprises in Nepal. One study has estimated that Nepal could have as much as one million bee colonies producing more than 10,000 mt of honey annually (FNCCI, 2003). The practice of colony migration, where the farmers transport their honeybee colonies near natural or forest areas has boosted up honey production and since some years Nepal has emerged as honey exporting country. Today the beekeeping program has been one of the integral parts of governmental policies as well as pursued by non-governmental organization for the upliftment of social and economical values of rural people of Nepal.

Apart from all these advantages, the beekeepers in Nepal are not able to capitalize full production potential. The honey productivity at national level is very low (25 to 30 kg/ colony/annum) from its production potential (70 to 80 kg/colony/annum) (FNCCI, 2003). One of the major causes behind low honey productivity might be pest and disease attack. Studies on enemies of honeybee by different authors in Nepal have listed many pests as major cause of colony depletion and low productivity; of which preying by hornets is one of the most important (Manandhar, 2000; Bista & Shivakoti, 2001; Ahmad et al., 2003; Bista, 2011; Aryal et al., 2015). Many species of hornet (Hymenoptera: Vespidae) are considered as major enemies of honeybees possessing serious threat to the beekeeping industry especially during colony migration. The genus *Vespa,* largest of the social hornets, is physically capable of preying on honeybees with ease. A persistent hornet attack weakens the colonies while a serious attack results in absconding or devastation of honeybee colonies. It becomes more serious as the hornet attack synchronizes with the dearth period for beekeeping.

Kafle (2012) has described that most troublesome among insects for bee colonies are the hornets and accounted the devastation of 32 colonies in 1968 at Sundarijal area of Kathmandu district. In Himanchal Pradesh, India, 20-25% of bee colonies deserted annually due to predatory activity of hornets (Adlakha et al., 1975). Akre and Davis (1978) reported that in Japan a group of 30 *Vespa mandarina* S. was able to kill 25,000 out of 30,000 bees in just three hours. It is estimated that in the course of life, a single female hornet uses 60-80 honeybees as food while the males live entirely on nectar (Hirschfelder, 1952). Hornet predation is even more serious at migration sites, which also is the natural habitat of *Vespa* species, where increasing number of honeybee colonies have increased the population of hornets and honeybee predation. Various control measures have been suggested against hornet menace, but all these seem to be either uneconomical or practically not feasible. In Nepal, the

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common practices followed by beekeepers is killing the hornet by flap, burning of hornet nest, use of poison baits, keeping guard at the apiary, but all of these practices increased the production cost with no stable solution. Thus this study was performed to understand the prey and predator activity patterns for the minimization of colony losses.

MATERIALS AND METHODS

The study was carried out for two years starting from 14 April, 2016 to 30 March, 2018 at two locations of Lalitpur district representing mid-hills of Nepal.

Study area

Study was undertaken at beekeepers' apiary at two locations of mid-hill areas of Lalitpur district: Dhapakhel, Lalitpur Metropolitan City-24 (1343-masl; N-27°38.17" and E-085°19.39") as Lalitpur rural and Charghare, Chapagoan, Godawari Municipality-10 (1473-masl; N-27°35.188" and E-085°18.738") as Lalitpur forest. Dhapakhel area regarded as rural location is accessible for transport, so migration of colonies is done during autumn and early spring seasons. This site consists of more *A. mellifera* colonies and few *A. cerana* colonies. Availability of feral *A. cerana* colonies is low. The major honeybee floras are mustard, maize, buckwheat, horticultural trees, ornamental plants and some forest trees. Settlement with open places and running water exists. The second site was at the outskirts of Chapagoan area near to the forest. This area is not well accessible for big vehicle, so migration of honeybee colonies are seldom. Both cultivated and feral *A. cerana* colonies exist in large number. Few domesticated *A. mellifera* colonies occur. Apart from the available floras of rural areas, the horticultural and forest plantation are more.

Preparation of study materials

The study was carried out on European honeybee, *A. mellifera* colonies at beekeepers' apiaries in both locations of Lalitpur district. Five colonies at each location were randomly selected from the apiary and managed throughout the study period following good beekeeping practices. The experimental colonies were prepared one month prior to the study maintaining new queen, five honeybee frames containing at least three frames with brood, honey and pollen. The honeybee queen was changed after one year following artificial queen rearing procedure.

Observation on hornets

Observation was made on two aspects: total number of hornets attacking at each colony and total numbers of honeybee preyed by the hornet. The incidence of hornets was studied for two years (14 April, 2016 to 30 March, 2018), while the hornet predation on honeybees was carried out for five hornet active months per year (30 June to 16 November, 2016 and 29 June to 16 November, 2017). Information on hornets hovering around the colonies was collected, the hornet passing by the colony or not performing the predatory position was not counted.

Data collection

Information of both study aspects were recorded outside the colonies at fortnightly intervals throughout the observation period. The number of hornets visiting the colonies and number of

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hornets predating on honeybees were counted following sight count method at five honeybee colonies in three different times of the day (9:00 to 9:30 AM, 12:00 noon to 12:30 PM and 15:00 to 15:30 PM) for three continuous minutes. The hornet species were collected using insect sweep net and were dry preserved. Collected hornets were identified at Entomology Division of Nepal Agricultural Research Council (NARC), Khumaltar, Lalitpur, Nepal. The weather parameters (Temperature, relative humidity and rainfall) of the observation dates were collected from meteorological observatory (1332-masl; N-27°39.07" and E-085°19.33") of National Agricultural Research Institute at Khumaltar, Lalitpur district, Nepal.

Data processing and statistical analysis

The number of hornet population and honeybee capture by hornet, recorded during three different hours of the day and from five honeybee colonies was pooled for their calculation on number of the observation day. The data were square root transformed wherever necessary. The capture rate (CR) of hornet, the defensive efficiency (DE) of colonies against hornet and the total predation of honeybees per day (PD) by the hornet was assessed following calculations given by Ibrahim (2009). ANOVA was performed to compare the incidence of predatory hornet and its predation rate on honeybees and the interactions between them. Means of the hornet incidence and predatory efficiency with different year, observation dates and study locations were separated using Tukey's Studentized Range Test (HSD) at 0.05 significance level. Relation between different weather parameters with hornet incidence and predation were conducted using Pearson's coefficient (P=<0.05 %) (SPSS 16.0, SPSS Inc., Chicago, IL, USA).

RESULTS AND DISCUSSION

Diversity of hornet (Hymenoptera: Vespidae)

The major species of hornet observed around the honeybee apiary at the study areas of both locations during the study period were: the yellow-legged hornet, *Vespa velutina* Lepeletier, 1836; black-bellied hornet, *Vespa basalis* Smith, 1852; greater banded hornet, *Vespa tropica* (Linnaeus, 1758) and Asian giant hornet, *Vespa mandarinia* Smith, 1852. Apart from this yellow-vented hornet, *Vespa analis* Fabricius, 1775 was also found but in few number. The yellow legged hornet, *V. velutina* was observed throughout the year, while other species were found during latter observation dates. Kafle (2012) described *V. basilis*, *V. orientaslis*, *V. mandarina*, *V. affinis*, *V. velutina* and *V. tropica* as the most troublesome among insects for bee colonies in different parts of Nepal. Similarly, Ranabhat and Tamrakar (2009) reported four species of hornets (*V. velutina*, *V. bicolor*, *V. tropica* and *V. basalis*) preying on honeybee, *A. cerana* at Kaski district of Nepal. The survey of hornets around honeybee apiary conducted around eastern and central parts of Nepal by Bista (2011) reported seven species of *Vespa* as, *V. analis*, *V. basalis*, *V. mandarinia*, *V. tropica*, *V. affinis*, *V. orientalis* and *V. velutina* (Bista & Dangi, 2012).

The Oriental and Palaearctic regions of the world are the evolutionary center of hornets (Genus *Vespa*). The subfamily Vespinae consist of four genera, Vespa Linnaeus, 1758; Provespa Ashmead, 1903; Dolichovespula Rohwer, 1916 and Vespula Thomson, 1869 (Carpenter & Kojima, 1997). Hornets are the largest known social wasps in the family

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Vespidae. There are twenty-three extant species of *Vespa* with seven fossil species more recognized till now. They are: *Vespa affinis* Linnaeus, 1764; *Vespa analis* Fabricius, 1775; *Vespa basalis* Smith, 1852; *Vespa bellicosa* de Saussure, 1854; *Vespa bicolor* Fabricius, 1787; *Vespa binghami* du Buysson, 1905; *Vespa crabro* Linnaeus, 1758; *Vespa ducalis* Smith, 1852; *Vespa dybowskii* Andre, 1884; *Vespa fervida* Smith, 1858; *Vespa fumida* van der Vecht, 1959; *Vespa luctuosa* de Saussure, 1854; *Vespa mandarinia* Smith, 1852; *Vespa mocsaryana* du Buysson, 1905; *Vespa multimaculata* Perez, 1910; *Vespa orientalis* Linnaeus, 1771; *Vespa philippinensis* de Saussure, 1854; *Vespa simillima* Smith, 1868; *Vespa soror* du Buysson, 1905; *Vespa tropica* (Linnaeus, 1758); *Vespa velutina* Lepeletier, 1836 and *Vespa vivax* Smith, 1870. The seven fossil species are, *Vespa bilineata*, *Vespa ciliate*, *Vespa cordifera*, *Vespa crabroniformis*, *Vespa dasypodia*, *Vespa nigra* and *Vespa picea* (Carpenter & Kojima, 1997; Kumar et al., 2015).

Most of these species have a distribution restricted to Asia, with highest diversity found in northern Indo-Malaya region. Among these, sixteen species are found in Indian subcontinent (Kumar et al., 2015). In Nepal, different studies reported presence of eleven species of genus *Vespa*, they are: *V. affinis*, *V. analis*, *V. basalis*, *V. bicolor*, *V. ducalis*, *V. fumida*, *V. mandarinia*, *V. orientalis*, *V. tropica*, *V. velutina* and *V. vivax* (Archer, 2012: Kafle, 2012; Bista & Dangi, 2012; Thapa, 2015).

Hornet incidence around honeybee apiary

The hornet incidence around honeybee apiary was studied throughout the year for two years. The hornet incidence at honeybee apiary was highly significantly difference between different years ($F_{1, 384}$=33.29, p=0.000), dates ($F_{23, 384}$=224.93, p=0.000) and locations ($F_{1, 384}$=23.09, p=0.000). Between interactions of different variables, the year with date ($F_{23, 384}$=20.77, p=0.000) and location with date ($F_{23, 384}$=2.14, p=0.002) were highly significant while year with location ($F_{1, 384}$=2.33, p=0.128) and year and date and location ($F_{23, 384}$=0.23, p=0.51) were not significantly different (Fig. 1 & 2, Table 1).

The first hornet visit was noticed during the month of April at both locations during both years. Except at rural area during 2016/017, the hornets visited apiaries from early-April. Its incidence was observed till early-December, thereafter for about four months the incidence of hornets was not noticed. This accounts that the hornet population incidence at honeybee apiaries persists for about eight months at both locations of mid-hill areas in Lalipur district.

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Table 1: Mean incidence and predation of hornet in *A. mellifera* apiaries at rural and forest locations of mid-hill areas in Lalitpur district during 2016/017 and 2017/018

Date	Mean incidence (No.) (±SE) (n=20 colonies)	Average predation (%) (±SE) (n=20 colonies)
Jan. Start to Mar. Mid	0.00 ± (0.00) i	
Apr., Start	1.05 ± (0.38) hi	
Apr., Mid	2.25 ± (0.38) ghi	
May., Start	3.25 ± (0.41) fghi	
May., Mid	5.35 ± (1.16) fgh	
June., Start	3.6111 ± (0.37) abcd	
June., Mid	5.5909 ± (0.52) fgh	
July., Start	7.40 ± (0.51) efg	20.58 ± (3.45) de
July., Mid	4.00 ± (0.69) fghi	18.76 ± (4.03) e
Aug., Start	7.95 ± (0.67) ef	25.85 ± (3.59) cde
Aug., Mid	18.75 ± (1.12) d	29.19 ± (2.28) bcd
Sept., Start	21.95 ± (4.92) d	34.24 ± (5.14) abc
Sept., Mid	31.90 ± (1.80) c	41.72 ± (2.98) abc
Oct., Start	57.50 ± (3.19) a	45.46 ± (1.73) abc
Oct., Mid	43.40 ± (2.87) b	49.57 ± (1.54) ab
Nov., Start	11.60 ± (1.08) c	54.93 ± (2.71) a
Nov., Mid	5.55 ± (0.53) bcd	53.39 ± (4.63) ab
Dec., Start	1.85 ± (0.30) hi	
Dec., Mid	0.00 ± (0.00) i	
Year	<0.001**	0.634 ^{ns}
Date	<0.001**	<0.001**
Location	<0.001**	0.252 ^{ns}
Year × Date	<0.001**	0.054*
Year × Location	0.13^{ns}	0.298 ^{ns}
Date × Location	0.002**	0.594 ^{ns}
Year × Date × Location	0.51 ^{ns}	0.989 ^{ns}

Data comprised of two year, two locations and observation taken fortnightly on incidence for two years and for predation during five hornet active months and same letter for mean incidence are not significantly difference (*P* ≤.005). ** = highly significant, *=significant, ns = non-significant

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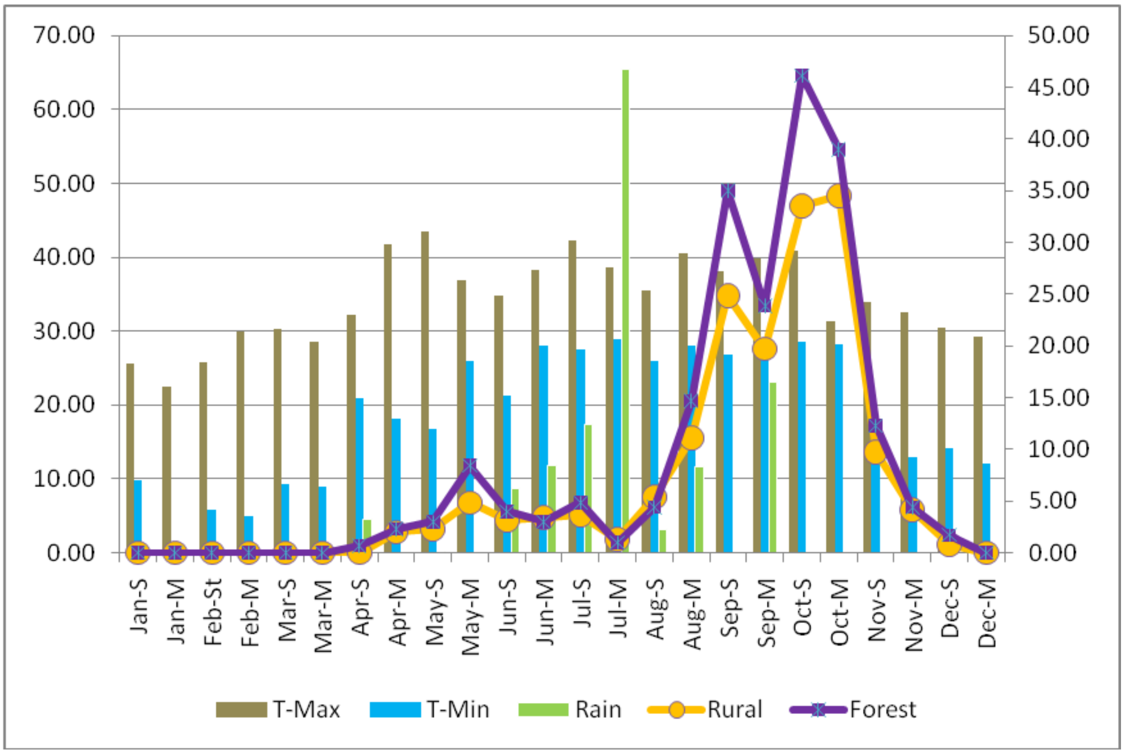

Fig. 1: Hornet incidence during different observation dates around honeybee apiary at rural and forest areas of mid-hills in Lalitpur district, 2016-017 [Values of Rural and Forest mentioned in primary axis; T-max, T-min and Rain in secondary axis; T-Max = Maximum temperature (°C), T-Min = Minimum temperature (°C), Rain = Rainfall (mm); S = Start of month, M = Mid of month]

The peak period of hornet incidence during 2016/017 at both locations was observed during September and October months. The population began to increase from the month of August and reached at maximum on early-October at forest locations and on mid-October at rural observation site. Thereafter the hornet population began to decrease and from mid-December their population was not noticed at the both observation sites. Another small peak of hornet incidence was also observed during mid-May at both locations, with average number of 11.8 and 6.8 hornets per three minutes count at forest and rural locations, respectively. During the entire observation dates the population of hornet was considerably higher at forest locations, except during mid-June, mid-July and early-August, where the population was little higher at rural locations. The maximum average population of hornet was 64.6 at forest observation site whereas at rural site it was 48.4 (Fig. 1).

Similar pattern of hornet incidence was observed during 2017/018, where the maximum population of hornet occurred during early-October at both locations. Other two small population peaks were observed during mid-August and early-July. During 2016/017, there were only two peaks observed whereas in 2017/018 three peaks were established. The average population during early-September in 2017/018 was highly affected due to heavy rainfall (36.5 mm) declining to 2.2 and 1.8 hornets at rural and forest observation sites. Also, the average hornet population was observed higher at forest location as compared to the rural observation site in most of the observation dates (Fig. 2). The maximum number of hornet count was 62.6 and 55.8 per three minutes at forest and rural locations, respectively. During

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both years, the incidences of hornet were not noticed from mid-December to the month of March. Ranabhat & Tamrakar (2008) during their study at Kaski district, Nepal reported the attack of hornet species on honeybees were higher from June/July to September/October while it was minimum during April/May and January/February. Recent study conducted at Solan, Himanchal Pradesh, India (1256-masl) by Brar et al. (2018) is also in accordance with present study, where the incidence of *V. velutina* was maximum in September followed by August, October, November and July. They also did not noticed hornet population during December to March. The hornet, *V. velutina* which is the exotic invasive pest in Europe and first reported from France in 2004, the seasonal incidence result at France is also similar to our study that the hornet activity was observed from July to December, with its activity peak during September and October (Monceau et al., 2013; Villemant et al., 2014).

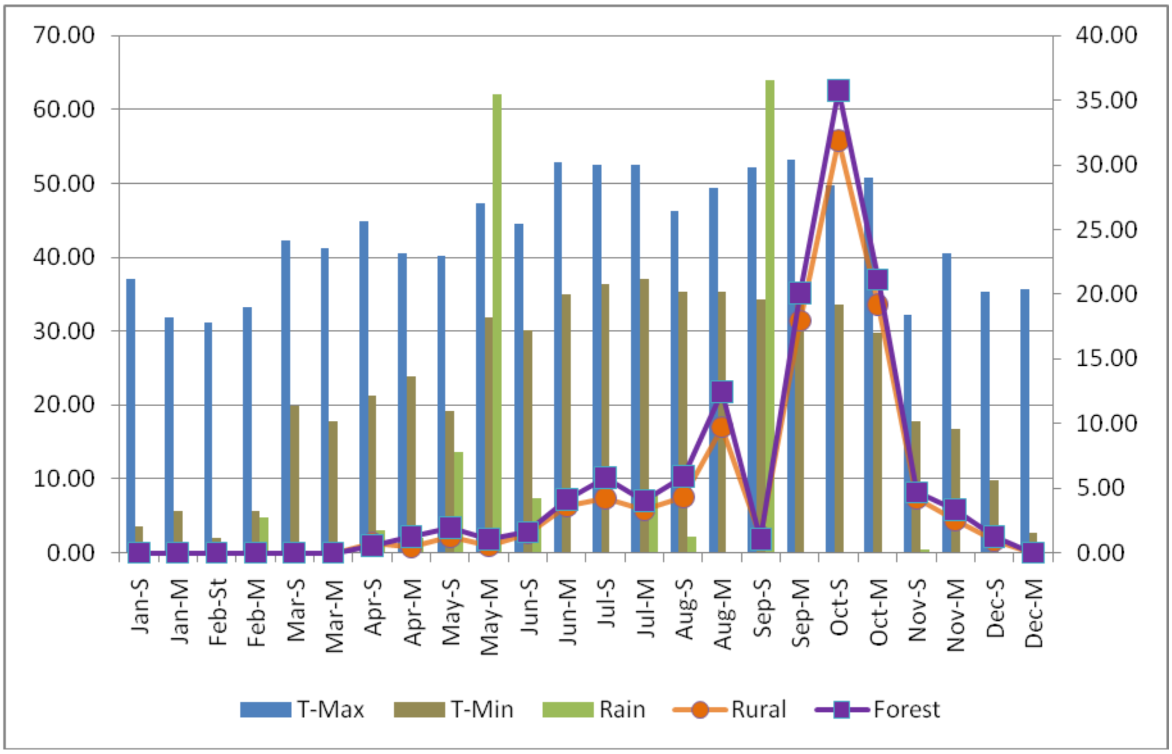

Fig. 2: Hornet incidence during different observation dates around honeybee apiary at rural and forest areas of mid-hills in Lalitpur district, 2017-018 [Values of Rural and Forest mention in primary axis; T-max, T-min and Rain in secondary axis; T-Max = Maximum temperature (°C), T-Min = Minimum temperature (°C), Rain = Rainfall (mm); S = Start of month, M = Mid of month]

In Asian hornets, the broods are fed with animal proteins (bees, insects, etc) while the adults rely on carbohydrates (nectar, ripe fruits, etc). The single mated queen, after emerging from winter dormancy during spring season, builds a primary cup-shaped nest, where she rears her first generation brood. The queen hornet during this period visit honeybee apiaries in search of honeybee as food to feed the brood. When the first generation brood has been emerged, the colony strength increases throughout the summer season reaching to peak during autumn and early winter season. During these periods, the hornet colony needs sufficient number of animal protein for food which could be available at honeybee apiaries (Matsuura & Yamane,

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1990; Shah & Shah, 1991; Monceau et al., 2013). Our study has displayed two to three population peaks of hornets; one as the major peak during September-October in both years, and remaining during mid-May in 2016/017 and during early-July and August in 2017/018, which resembles with the biology of hornet at the studied locations.

Relation between hornet incidences with weather parameters

Like most of the insect species, the foraging activities of hornet are also influenced by the weather parameters, important being temperature, humidity, wind and rainfall. The hornet incidence around the honeybee apiary at both locations were negatively correlated with rainfall but were positively correlated with maximum and minimum temperature. The result of correlation with relative humidity was contrasting, the hornet population was found negatively correlated at forest area and positive at rural area (Table 2). The rainfall seems to be inflicting factor for hornet visit around the apiary because the population of hornet were observed lower during the rainy days. Similar correlation effect was established between incidence of V. *velutina* with temperature and relative humidity at Solan, Himanchal Pradesh, India where the authors found positive relation (Brar et al., 2018). Sharma and Mattu (2014) also found positive correlation between number of *V. velutina* and *V. mandariana* honey bees with temperature and relative humidity.

Table 2: Pearson's correlation of hornet incidence with weather parameters at two locations of mid-hill areas in Lalitpur district

Particulars	Rural area	Forest area
Maximum Temperature (°C)	0.118 (0.621)	0.14 (0.555)
Minimum Temperature (°C)	0.282 (0.228)	0.294 (0.209)
Relative Humidity (%)	0.003 (0.991)	-0.006 (0.979)
Rainfall (mm)	-0.373 (0.105)	-0.381 (0.098)

Data in parenthesis represents a probability value (P=<0.05 %)

Predation by hornet on honeybees

The total predation rates of the hornet were not significantly difference between the year ($F_{1, 160}$=0.23, p=0.64) and two locations ($F_{1, 160}$=1.32, p=0.252) but were significantly different in different dates ($F_{9, 160}$=13.58, p=0.000) of the districts (Fig. 3 & 4, Table 3). Similarly, the hornet predation between year and location ($F_{1, 160}$=1.092, p=0.298), date and location ($F_{9, 160}$=0.826, p=0.594) and year, dates and locations ($F_{9, 160}$=0.23, p=0.989) were not significantly different, however the year and date interaction was nearly significant ($F_{9, 160}$=1.913, p=0.054) (Fig. 3 & 4, Table 1).

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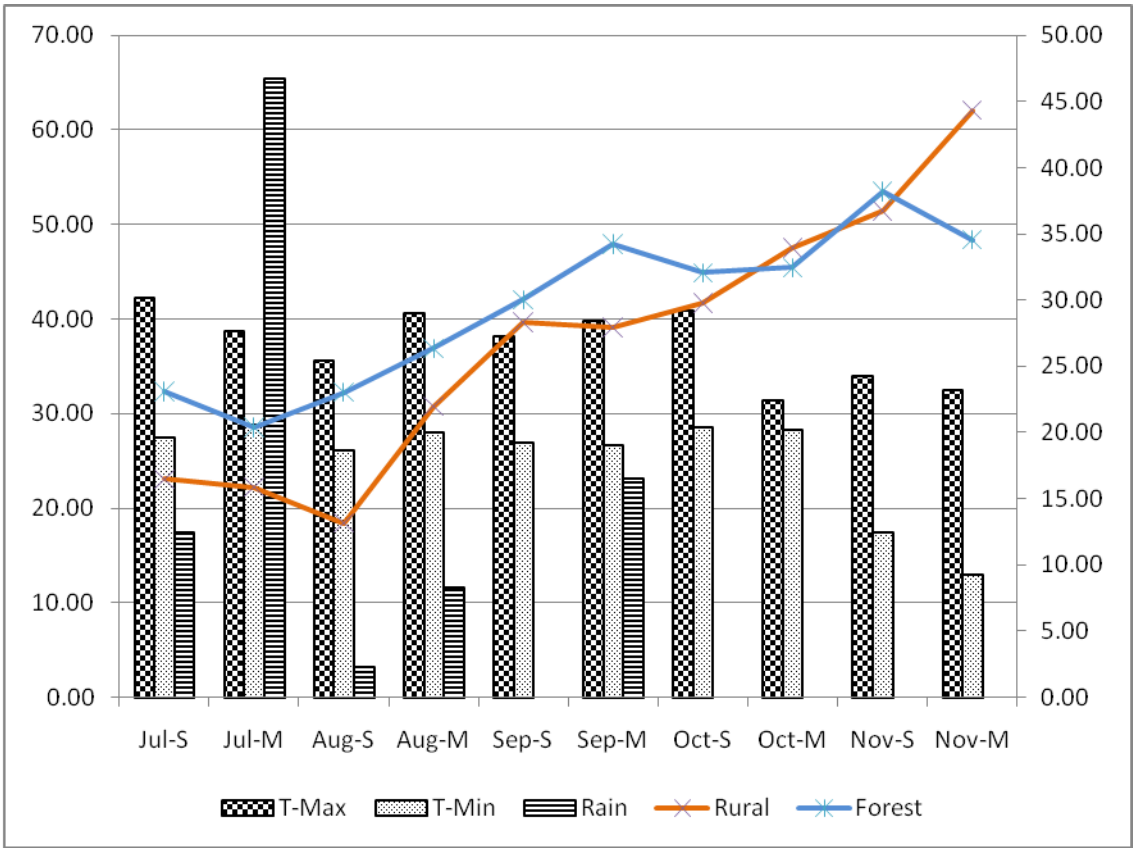

Fig. 3: Percentage predation by hornet on honeybees during hornet active period around honeybee apiary at rural and forest areas of mid-hills in Lalitpur district, 2016
[Values of Rural and Forest mention in primary axis; T-max, T-min and Rain in secondary axis; T-Max= Maximum temperature (°C), T-Min= Minimum temperature (°C), Rain=Rainfall (mm); S=Start of month, M=Mid of month]

The population of hornet was observed lower in spring and early summer, thereafter gradually increased to maximum during autumn season. The predation percentage also increased in a similar trend. It was lower during the early observation period then gradually increased exhibiting maximum predation in the latter days of observations during both years at both locations. A small decrease in predation was observed on early-August (18.42 %) at rural location and mid-July (28.57%) at forest location during 2016 (Fig. 3). Similarly, during 2017, the predation declined on mid-August (25.88%) at rural area and mid-July (22.22%) at forest location (Fig. 4). The maximum predation by hornets were observed on mid-November (62.07%) and early-November (53.49%) at rural and forest locations, respectively during 2016. In 2017 the highest predation was observed in early-November (70.27%) at rural location while it was mid-November (58.62%) in the forest observation site. The predation rate by the hornet on honeybees and predating trend at both rural and forest locations seems to be somewhat similar. During 2016, the predation was observed higher at forest location throughout the observation dates except during mid-October and mid-November where predation was little bit higher at rural location. But during 2017, predation rate at both locations showed ups and downs and at the end of observation dates the predation at rural area was observed higher.

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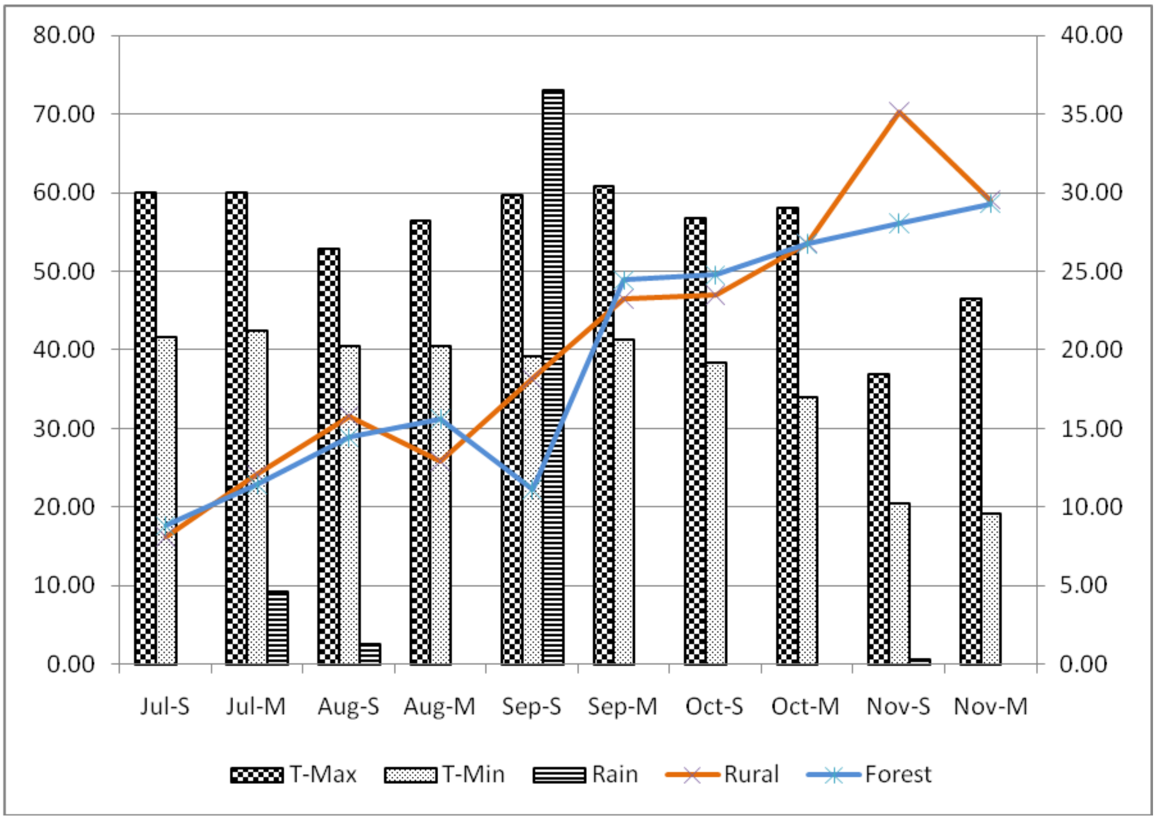

Fig. 4: Percentage predation by hornet on honeybees during hornet active period around honeybee apiary at rural and forest areas of mid-hills of Lalitpur district, 2017
[Values of Rural and Forest mention in primary axis; T-max, T-min and Rain in secondary axis; T-Max= Maximum temperature (°C), T-Min= Minimum temperature (°C), Rain=Rainfall (mm); S=Start of month, M=Mid of month]

Relation between hornet predation with weather parameters

The hornet predation on honeybees was found mostly negatively correlated with existing weather parameters (Table 3). Both maximum and minimum temperatures were negatively correlated and highly significant indicating the efficiency of hornet to catch honeybees is low during high or low temperature ranges. Rainfall is observed as major factor for hornet predation activity which was negatively correlated in both study areas. The hornet incidence and its predation rate to honeybees were positively correlated at both areas of mid-hill areas in Lalitpur district specifying predation severe with higher number of hornet visits at apiary.

Table 3: Pearson's correlation of hornet predation with weather parameters and hornet incidence at two locations of mid-hill areas in Lalitpur district

Particulars	Rural area	Forest area
Maximum Temperature (°C)	-0.644** (0.002)	-0.535* (0.015)
Minimum Temperature (°C)	-0.771** (<0.001)	-0.657** (0.002)
Relative Humidity (%)	0.072 (0.762)	-0.036 (0.882)
Rainfall (mm)	-0.344 (0.138)	-0.423 (0.063)
Hornet Incidence	0.259 (0.271)	0.233 (0.322)

Data in parenthesis represents a probability value (P=<0.05%)

ISSN: 2661-6270 (Print), ISSN: 2661-6289 (Online)
DOI: https://doi.org/10.3126/janr.v3i1.27105

Table 4: Average hornet capture rate (CR), total predation per day (PD) and honeybee defensive efficiency (DE) during hornet active period around honeybee apiary at two locations in Lalitpur district during 2016 and 2017

Observation dates	Lalitpur Rural			Lalitpur Forest		
	CR	PD	DE	CR	PD	DE
July, Start	19.65	1.20	80.35	25.00	2.00	75.00
July, Mid	23.18	0.90	76.82	25.71	1.00	74.29
August, Start	25.00	1.90	75.00	30.55	2.50	69.45
August, Mid	28.33	4.60	71.67	34.04	7.20	65.96
September, Start	38.01	7.30	61.99	32.13	10.50	67.87
September, Mid	42.81	12.70	57.19	48.38	16.60	51.62
October, Start	44.33	22.90	55.67	47.21	30.00	52.79
October, Mid	50.55	20.50	49.45	49.47	22.30	50.53
November, Start	60.87	6.10	39.13	54.79	6.90	45.21
November, Mid	60.58	3.10	39.42	53.50	3.20	46.50

[CR= Hornet capture rate (%), PD= Total predation per day, DE= Honeybee defensive efficiency (%)]

The total capture rate of honeybees by the predatory hornets was found in increasing trend from July to November at both locations. The rate of capture at forest location was comparatively higher than at rural locations, however during the mid-October and in the month of November it was higher at rural location. Similarly, the defensive efficiency of honeybee against hornet was good during the early observation which decreased simultaneously in latter observation days. The per day average total predation by hornet was higher during the month of October at both locations, which was maximum during early-October observation dates (22.9 and 30.0, respectively at rural and forest locations). The average predation per day was observed comparatively higher at the forest area than at rural location (Table 4).

The fluctuation of hornet population dynamics on honeybee apiary is mainly governed by weather factors and seasonal hornet biology. Mild temperature without rainfall induces the visitation and predation rate of hornet to the honeybees. From the late spring to the end of autumn season, at the time of brood rearing and colony growth period of hornets, the demand for protein increases which explains the increase of the predation pressure on apiary from mid-July to late November (Fig. 3 & 4). Monceau et al. (2013) and Matsuura & Yamane (1990) also elucidated similar biological facts of hornets and explains the predation pressure from early July to late October. The pressure of predation increased up to 70.27% in our observation at rural location during early-November 2017. Hornet catches honeybee around the apiary and the most vulnerable are the forager honeybees due to their extra load of nectar or pollen with them, with these loads they have little chances to escape or defend against the predatory hornets. Monceau et al. (2013) found that the forager honeybees are often subjected to predation by *V. velutina* due to their pollen or nectar loads which can represent up to 40% extra body mass.

Many authors have studied the prey spectrum of hornet from its nest and found brachycera, dipterans and social hymenopterans, mainly bumblebees and honeybees are the main preys (Williams, 1988; Abrol, 1994). Villemant et al. (2011) showed the real preference by the hornet social Hymenoptera [honeybees (37%), common wasps (18%)] as well as other such as hoverflies (Syrphidae) and necrophagous Diptera, such as carrion and house flies (34%). Predation rate by the hornets during the early observation dates was comparatively low at

ISSN: 2661-6270 (Print), ISSN: 2661-6289 (Online)
DOI: https://doi.org/10.3126/janr.v3i1.27105

both locations. During early-July observation date was 16.22% and 17.65%, respectively at rural and forest locations (Fig. 4). Although the rate of predation increased from early spring to late autumn, during most of the observation dates the hornet attack was not always successful. But still, the hornets visited continuously around the apiaries throughout the day. Perrard et al. (2009) in France have found that the hornet needs in an average of four trails to catch one honeybee during its peak predation period.

At the experimental apiary in both locations, the preference of hornet visit was observed higher towards the *A. mellifera* colonies. Only few hornet population visited at *A. cerena* colonies, particularly during the autumn and early winter season. Throughout the study period, the predation rate on *A. cerana* honeybees was comparatively low as compared to that of *A. mellifera*. The native honeybee, *A. cerana* and hornet have inhibited same ecological habitat since time immemorial and have both developed survival strategies. Many researchers have discussed the defensive behavior like, bee-carpet, heat balling, abdomen shaking, creating some sound, zig-zag movement towards colony by *A. cerana* against predatory hornets, which the exotic honeybee species, *A. mellifera* do not possess such behavior or perform with less efficiently (Matsuura & Yamane, 1990; Shah and Shah, 1991; Abrol, 1994; Ranabhat and Tamrakar, 2008; Perrard et al., 2009; Villemant et al., 2011, 2014; Monceau et al., 2013; Author personal observations).

CONCLUSION

Beekeeping has been practiced in Nepal since long time for variety of purposes including social, economic, religious, health and other parts of the social life. Before two and half decades ago, no fundamental problems existed on beekeeping, but after the introduction of *A. mellifera* the intensity of both native and invasive pest pressure has increased. Hornet predation is one these problems influencing both stationary and migratory beekeeping nowadays. Its incidence and predation were observed low in early spring and summer then gradually increased to the highest peak during autumn particularly on October and November in different capacities at both rural and forest locations. Thereafter the number declined abruptly by the December and no hornet was noticed during winter and early spring period. Assessing the temporal and spatial population variations and predation along with weather parameters will be helpful in decision making to develop sustainable management plans against hornets.

ACKNOWLEDGEMENTS

The research is funded and supported by NARC. Authors are thankful to Satyam Beekeeping Center, Lalitpur for providing their apiary for research work. Special thanks for Mr. A. Shukla, prominent beekeeping expert of Nepal for guiding during field work. Also thanks to Mr. Ujjwal Shrestha, Godavari Municipality-11 and Mr. Dharma Shrestha, Lalitpur Metropolitan City-22 for providing their apiaries for additional observations works.

Author Contributions

ISSN: 2661-6270 (Print), ISSN: 2661-6289 (Online)
DOI: https://doi.org/10.3126/janr.v3i1.27105

S.B. planned the research, conducted the study, analyzed the data and wrote the manuscript; R.B.T., G.B.K., S.B.P. and Y.N.G. assisted on planning and conducting the research work; S.A. assisted in analyzing the data and on preparing the paper.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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